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# Gravity ventilation for interior bathrooms

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# Gravity ventilation for interior bathrooms

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**Abstract**. Based on the extensive experience of a building cooperative with interior bathroom gravity (shaft) ventilation in existing apartment buildings, the replacement buildings constructed at the same location are also equipped with gravity ventilation. The aim of the project described here is to demonstrate the possibilities and limitations of gravity ventilation in one of the new replacement buildings by means of monitoring. Detailed monitoring over a complete year recorded the behaviour and effectiveness of the gravity ventilation in all seasons. In winter, gravity ventilation leads to higher air change rates in interior bathrooms than in summer. In general, humidity can be removed with gravity ventilation except in summer, when after a shower the bathroom door stays closed for 24 h. In summer when the indoor and ambient temperature is the same the gravity ventilation does not work. In this case, the interior bathroom should be ventilated by the main apartment ventilation, e.g., while the bathroom door and other room doors and windows are open at the same time. In summer, doors and windows are often open and the gravity ventilation summer problem can be viewed as negligible. Therefore, gravity ventilation is a good alternative to other ventilation systems in interior bathrooms.

## 1. Introduction

High moisture and odor loads in bathrooms and toilets require special attention to their ventilation. If no mechanical ventilation system is available, the required air exchange in interior bathrooms and toilets must be ensured differently. Often, decentralized exhaust fans are used for air extraction. Another possibility is gravity ventilation (shaft ventilation). An example of this is “Kölner Lüftung” [1] where fresh air is collected at basement level and led through a duct into the interior bathroom/toilet. The supply air inlet (valve) in the room is at floor level. The exhaust air valve is close to the ceiling and the air is discharged via the roof. Each bathroom has its own supply and exhaust ducts. As gravity ventilation depends on pressure differences over the building height, it cannot be controlled and varies seasonally. Gravity ventilation requires few or no technical components (e.g., controllable supply air valve). It is a low-tech natural ventilation system.

With detailed monitoring the efficiency of the “Kölner Lüftung” gravity ventilation in interior bathrooms is examined over a whole year. Since gravity ventilation leads to an uncontrolled air exchange without heat recovery, it is also investigated how this affects energy consumption.

## 2. Methodology

In 2021 a new replacement apartment block was built with manual window ventilation for the main apartment and “Kölner Lüftung” gravity ventilation for interior bathrooms/toilets (figure 1). The gravity ventilation of eight interior bathrooms split into two stacks of four are examined. The flow velocity and direction as well as temperature and relative humidity are measured in all supply and exhaust ducts, and temperature and relative humidity in all bathrooms are logged. In addition, all doors and windows are equipped with opening contacts to allow for the evaluation of the impact of their position on air flow rates. The supply air valve is connected to the bathroom light and opens completely when the light is switched on. After the light is switched off, the valve stays open for five to eight minutes before it slowly closes to a minimum opening position. The exhaust air valve is always 100 % open.

The measurement data from the ducts are recorded via a remotely accessible programmable logic controller (PLC). The bathroom air and door/window opening contacts data loggers are manually read approx. every two months. All values measured are logged every two seconds. The door and window contacts do not provide information on how far the door or window is open when "open". The opening width is between ajar and 100 % open.

The ambient climate data are taken from the Meteoschweiz Basel-Binningen climate station. The results comprise the period 08.03.2022 – 06.01.2023.

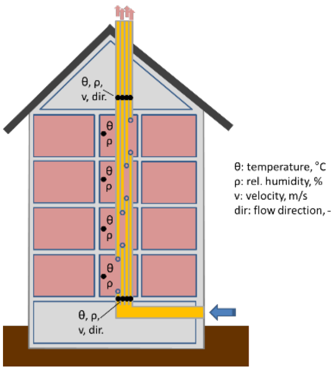


**Figure 1.** Principle sketch of "Kölner Lüftung" gravity ventilation and sensors in interior bathrooms, supply ducts at cellar level and exhaust ducts at roof level.

## 3. Results and analysis

Figure 2 shows two evening showers with a closed bathroom door afterwards. During shower times, the relative humidity quickly reaches approx. 100 % (Figure 2 c, green line). After each shower the door stays open for approx. 15 min (Figure 2 a, orange line) and the bathroom air mingles with the apartment air. Other room doors and/or the windows are closed in the example shown. After the showers the relative humidity decreases quickly to 68 % and 76 % respectively (figure 2 c, green line). After the second shower and 15 min bathroom door opening time, the bathroom door is closed and stays closed for about 4.5 hours (Figure 2 a, orange line). After closing the bathroom door, the relative humidity increases from 68 % to approx. 88 %. Approx. 2.5 hours later the relative humidity is down to 62 % and after total 3.5 hours below 60 %. During these 3.5 hours the air flow velocity in the exhaust duct is around 0.6 m/s which corresponds to an air change rate for the interior bathroom of 1.0 $h^{-1}$. The air flow velocity in the supply duct is lower because the supply air is partly fed through the leaky installation shaft (Figure 2 a, red/blue lines).

As the temperature difference between bathroom and supply air is about 8-10 K (Figure 2 b, green/blue lines), the characteristics shown are for a transitional season. Even with a closed bathroom door the necessary dehumidification of the interior bathroom can be ensured.

At about 2:45 am the bathroom door is opened again. It can be seen that the relative bathroom humidity increases very slightly to 64-68 % as the bathroom air mingles with the apartment air. As the relative humidity stays constant it can be stated that the impact of the gravity ventilation on the apartment ventilation is non-existent or at most negligible.

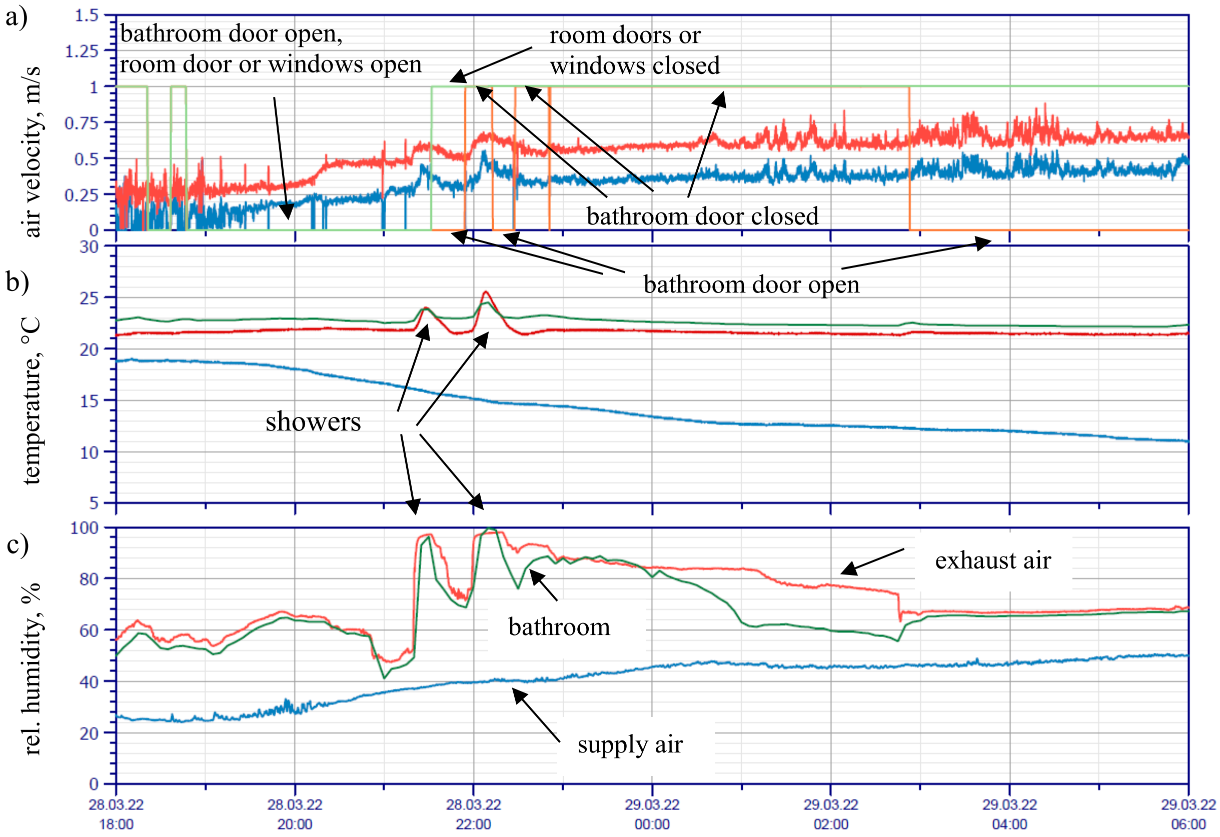


**Figure 2.** Showers with bathroom door closed afterwards: a) air velocity in supply and exhaust duct and opening status of doors and windows (bathroom door orange line: closed = 1, open = 0, window/room door green line: closed = 1, open = 0), b) temperatures in supply/exhaust duct and bathroom, c) relative humidity in supply/exhaust duct and bathroom (measurements: 2 sec time steps).

In order to avoid moisture damage, according to SIA 180 [2] the relative humidity must not exceed certain daily average limits depending on the ambient and room air temperatures. Figure 3 a-d show this for the “west bathroom stacks” for the case "bathroom door closed". It can be assumed when the bathroom door is closed that the air exchange in the bathroom is induced (as far as possible) by gravity ventilation. Since the bathroom air temperatures are generally between 20-25 °C, the maximum permissible daily average values of the relative humidity are given for the room air temperatures of 20 °C and 25 °C. It is easy to see that on most days the humidity values measured are below the maximum permissible daily mean values, even when the bathroom door is closed. Since the bathroom door is mainly closed during showering and a short period afterwards, i.e. high loads are present, this is the worst case. It should be noted that the daily values shown for "bathroom door closed" are not based on standard-compliant 24-h average values, but on average values over the closing time of the bathroom door. This can be as little as 30 minutes on one day.

However, since the bathroom doors are open most of the day, the case "all states" in Figure 3 e-h are "real" daily mean values and are also interesting for an overall assessment. “All states” means open/closed bathroom doors and open/closed doors/windows from other rooms. In these cases, the relative humidity shifts to lower values as expected, because the bathroom is in air exchange with the apartment and sometimes additionally with the ambient air via open windows. The limit value for the relative room humidity is complied with on almost all days.

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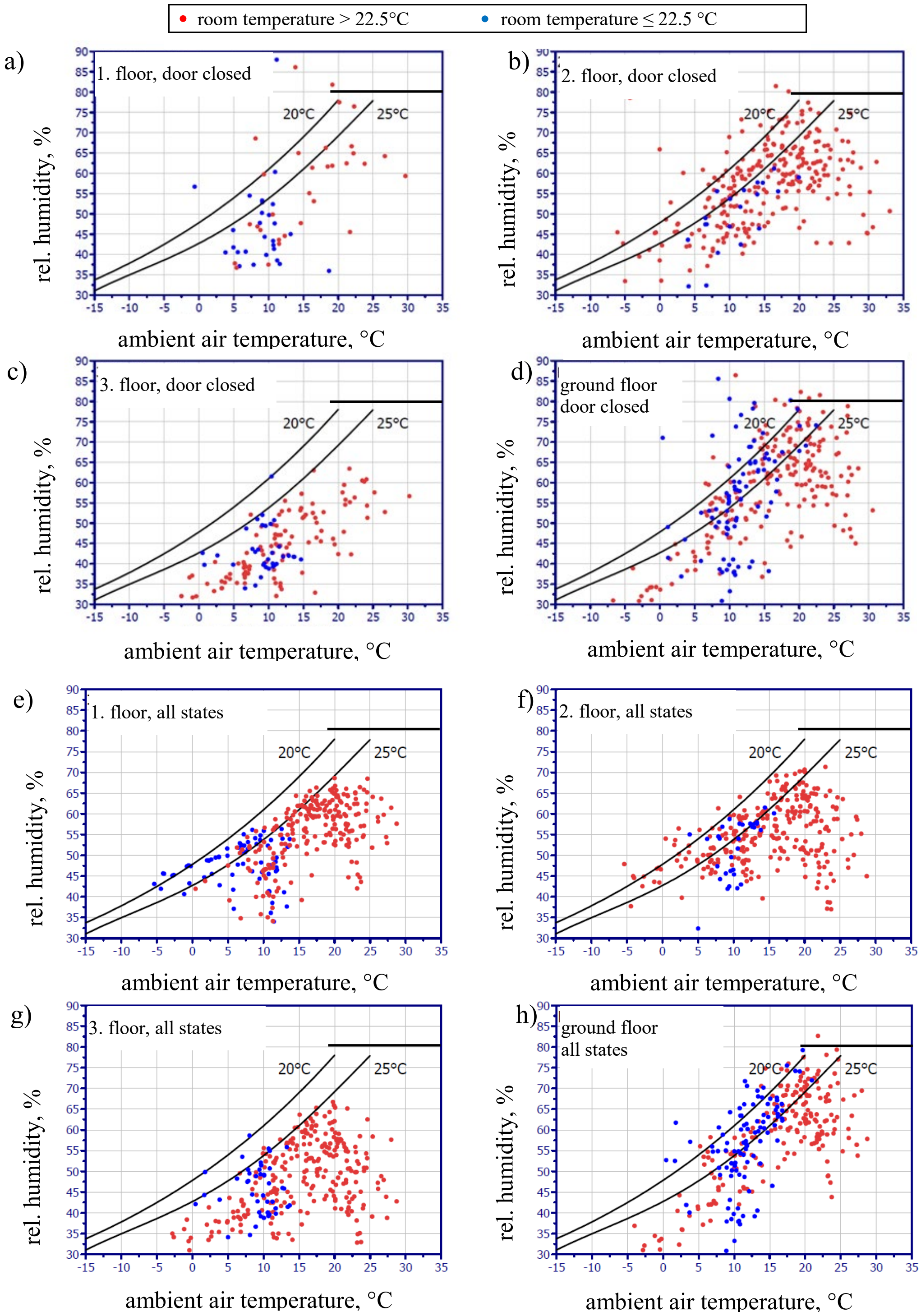


**Figure 3.** Maximal allowed daily mean values of relative humidity depending on daily mean values of bathroom and ambient air temperatures according to SIA 180 for the west bathrooms: "bathroom door closed" (a-d) and "all states" (e-h) (evaluation based on measurements: 08.03.2022 – 06.01.2023).

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The monthly mean values of relative humidity of most bathrooms are between 45-65 % with strongly fluctuating standard deviations (figure 4 a). The values shown include situations with open/closed bathroom doors and doors/windows in other room. The ground floor bathroom shows the highest humidity values in Mai/June compared to the other bathrooms. It complies to figure 3 h. In summer, the monthly mean value of air change rate is the lowest (figure 4 b). This is based on the lower temperature differences between bathrooms and ambient in summer. It should be noted that the shown air change rate is based on exhaust duct values only. In summer when all doors and windows are open it is assumed that the real bathroom air change rates are higher than shown in figure 4 b.

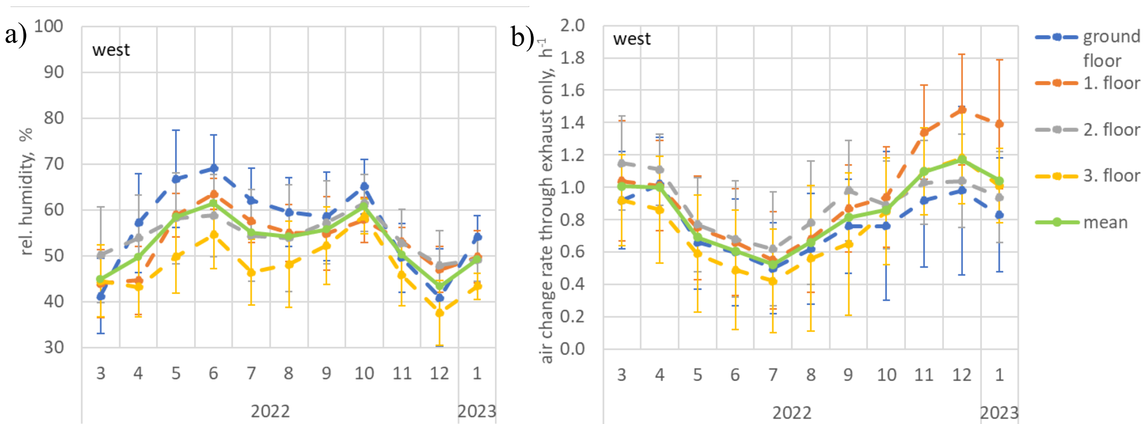


**Figure 4.** Monthly mean values of relative humidity (a) and air change rate through exhaust ducts only (b) for the west bathrooms for "all states" (evaluation based on measurements: 08.03.2022 – 06.01.2023).

The comparison between the heating consumption measured and the calculated heating demand shows that the climate adapted consumption is 10 % higher than the demand. This is within the range of what can be expected according to the literature due to user influence of ± 50 % [3]. It can therefore be assumed that the additional heating consumption is due to user behavior and that the gravity ventilation does not lead to increased heating consumption.

## 4. Conclusion

The results clearly show that various parameters have an influence on ventilation rates for gravity ventilation systems. The main ones are

- the bathroom/environment temperature difference
- if bathroom doors are closed or open with/without connection to ambient air via open room doors and windows

The flow velocity in the exhaust air duct is almost always higher than in the supply air duct. This means that there are usually higher volume or mass flows in the exhaust air duct than in the supply air duct. Thus, in addition to the air from the supply air duct, the exhaust air of gravity ventilation also contains air from the leaky installation shaft that is located in the bathroom (bathroom door closed) and the rest of the apartment without/with open room doors and windows (bathroom door open).

In the interior bathrooms studied, the doors are open for more than 90 % of the time. If the bathroom door is open, the bathroom is in air exchange with the apartment and the relative humidity levels with the rest of the apartment. However, the effect of gravity ventilation on the ventilation of the entire apartment is very small. If the bathroom is connected to the ambient air via open doors and windows, the bathroom is ventilated via normal apartment window ventilation, and it is assumed that the bathroom air exchange rates will be higher than given for the cases "all states".

In winter, when the windows are mainly closed, gravity ventilation results in the greatest air changes in the bathroom due to the high temperature differences between the bathroom and the ambient air and the humidity of the interior bathrooms is rapidly removed when the bathroom doors are closed. In summer, the temperature differences between bathroom and environment are small. This leads to a lower air exchange rate when the bathroom door is closed. In addition, the ambient air has a high relative humidity in summer and this, in combination with the lower air changes, leads to an increase in the time necessary for the removal of humidity.

In general, SIA 180 allows variable relative humidity limits depending on the daily mean room and ambient temperatures. These limits are only exceeded on a few days.

The worst case for the gravity ventilation is warm summer days, when the temperature difference between the bathroom and ambient is very small and the bathroom door remains closed for 24 hours after a shower. However, this is certainly a very unlikely scenario in real use. To exclude this case, the air exchange and thus the drying of the interior bathroom should be supported on such summer days with an open bathroom door and open apartment windows.

The gravity ventilation does not lead to any noticeable increase in heating consumption. Thus, gravity ventilation as a type of low-tech ventilation is a good alternative to other forms of ventilation in interior bathrooms.

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